

# WQ2000: WATER QUALITY MODELLING ASSESSMENT SYSTEM

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## ABSTRACT

*WQ2000 is an interactive system for rapidly assessing quaternary catchment salinity for naturalised and developed conditions. This Water Research Commission product can also provide a regional overview of salinity conditions. It incorporates powerful and flexible "What if?" capabilities for assessing proposed new developments.*

*A simple to use but versatile interface links the user to an extensive database and facilitates interaction with the sophisticated WQT monthly time step hydro-salinity model. The database contains monthly time series of rainfall, naturalised pervious and urban catchment runoff, calibrated WQT model hydro-salinity parameter values and a wide range of natural and present day development characteristics. Metadata is provided for all of the default data. The initial implementation is for the 192 quaternary catchments of the Vaal River, ranging from undeveloped areas to some of the most developed catchments in South Africa.*

*After selection of a quaternary catchment, the WQT hydro-salinity model is run for seventy years of monthly hydrology for natural and present day developed conditions for both incremental and cumulative cases. These four simulations are run seamlessly and invisibly without the user needing any expertise in using the complex WQT model. Any of the default values can be changed to reflect the impact of expected or planned developments. All user changes are tracked in the metadata for each user-generated project. The results for the selected catchment can be displayed and printed in tabular form and as time series and duration curve plots. Segmented bar plots for a number of quaternary catchments can also be produced.*

*A user support system is being implemented by the DWAF. Two training days have been held, and others are expected to follow. Provision is being made to centrally assimilate modifications and to periodically disseminate new base data to registered users.*

*The model basis, its structure, uses, limitations and potential enhancements are discussed.*

## INTRODUCTION

WQ2000 was developed and enhanced under contract to the RSA Water Research Commission<sup>(1,2)</sup>. It is an interactive computer system for rapidly assessing quaternary catchment salinity for naturalised and developed conditions. It can also be used to provide a regional overview of salinity conditions. WQ2000 incorporates powerful and flexible "What if?" capabilities for assessing the impact of proposed new developments.

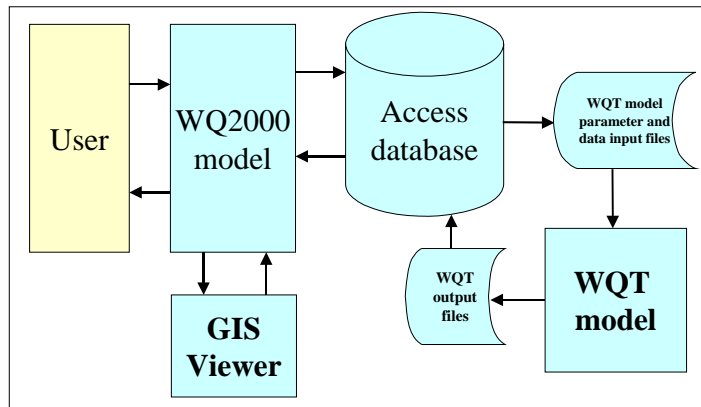
### System overview

WQ2000 incorporates a simple to use but versatile interface that links the user to an extensive database, the sophisticated WQT monthly time step hydro-salinity model and the Department of Water Affairs' (DWAF) GIS Viewer<sup>(2)</sup>. The WQ2000 model layout is shown in Figure 1.

The database contains seventy-year monthly time series of rainfall, naturalised pervious and urban catchment runoff and calibrated WQT hydro-salinity model<sup>(3)</sup> parameter values. The intrinsic characteristics of each quaternary catchment are stored, including catchment area, mean annual

precipitation, mean monthly evaporation, mean annual runoff, Symons Pan to catchment and lake evaporation factors and the linkage to adjacent quaternary catchments.

The database includes default information on present day development, including urbanisation, irrigation, wetlands, bed loss, major and minor dams, mine and effluent discharge, water importation and abstraction. Altogether the database contains over 1300 fields of information to describe each quaternary catchment.



**Figure 1: WQ2000 model structure**

The initial implementation is for the 192 quaternary catchments of the Vaal River covering three Water Management Areas. The WQT model was calibrated for this area during the DWAF Vaal River Water Quality Update study<sup>(5,6,7,8)</sup>. These range from undeveloped areas to some of the most developed catchments in South Africa. The intention is to extend this coverage to the remainder of the country.

#### Model uses

WQ2000 facilitates rapid initial assessment of the impact of proposed development options including:

- Introduction of new dams or changes to existing ones
- Alteration or introduction of new mine or effluent inputs
- Alteration of quantity or quality of the water imported to the catchment
- Change to water abstraction or minimum release from dams
- Growth in urban area or the density of the paved portion of urban area
- Change in irrigated areas supported and unsupported by farm dams or with their supply regulated by the main stem river system as well as the proportions of catchment runoff entering upstream of each category
- Change in wetland area or channel bed loss.

An overview showing the state of the quaternaries within a defined catchment can also be generated using the DWAF's GIS Viewer.

#### Actions performed

After selecting a quaternary catchment and, if desired, changing default development data to reflect the option to be examined, the model simulation is performed. The WQT hydro-salinity model then simulated seventy years of monthly hydrology for the following four scenarios:

- Natural conditions for the quaternary itself (off-channel with no influence from upstream catchments)
- Natural conditions with dilution (or pollution) from upstream catchment inflow
- Present day development state for the quaternary catchment alone
- Present day development state with cumulative inflow from upstream catchments.

Menu options are provided to display the results or to depict a catchment overview.

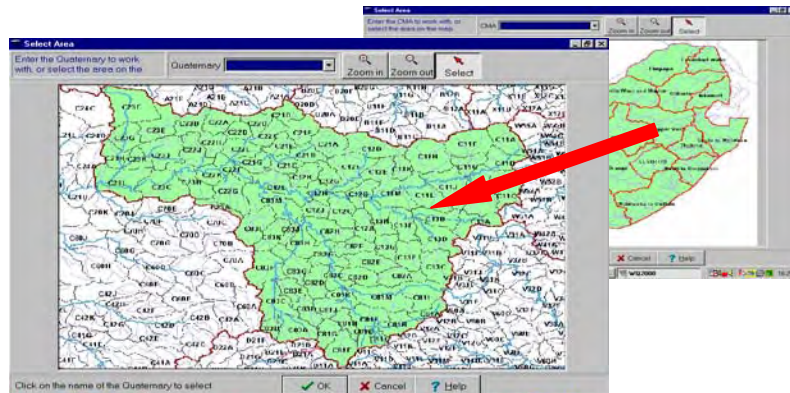
#### Skill requirements

A particular strength of WQ2000 is that in-depth knowledge of the underlying WQT model is not required to rapidly simulate development changes. (Such specialised skills are required only for the initial model calibrations and population of the database, which has already been done for the Vaal River catchment.) The main requirement is that the user should be conversant with water resources systems and be able to interpret the flow and water quality results.

## USING WQ2000

### Project database

The user may not edit the default database of catchment characteristics and present day information. Instead this information is copied into one or more user-defined project databases which can be progressively modified to reflect known changes since September 1995 or the specific development option that is to be simulated. Creation of a new project database or selection of an existing one is quickly and easily done using the start menus.



**Figure 2: Selection of quaternary catchment from map**

### Selection of Quaternary catchment

The user is next prompted to select a quaternary catchment. This can be done by direct entry of the quaternary code (e.g. C11C) or by selection from maps of water management areas (Figure 2).

### Editing default data

The user can elect to edit one or more of the default data values for the selected a quaternary catchment. The menu provides three tabs for this purpose. Figure 3 shows changes made via the "Physical data 1" tab.

	Quaternary	Upstream	
Catchment area	200	0	km²
Impervious urban area	0	0	km²
[1] Wetland Area	0	0	km²
[2] Bed Loss	0	0	mill.m³/year
[3] Effluent inflow volume	0	0	m³/day
[3] Effluent	0	0	m³/day
[4] Water demand from	0	0	mill.m³/year
[5] Water demand from	0	0	mill.m³/year
[6] Importation volume	113.18	0	mill.m³/year
[6] Importation TDS	112	0	mg/l

**Figure 3: Data changes via tab "Physical Data 1"**

In the example the field "Catchment area" is highlighted in yellow. This indicates that the area of "200" km<sup>2</sup> has been changed from the previous default value. Double clicking on this field would restore the default value, while selecting the "Save" button would set the new default area to 200 km<sup>2</sup>. The "Wetland area" is highlighted in red, indicating that an invalid (in this case non-numeric) or out of range value has been specified. Resting the cursor on a field or its description produces a pop-up note giving further description of the item (in this case for the effluent inflow volume). A user manual can also be accessed via the Help menu. Resting the cursor over the field itself displays a pop-up note (not shown) of the metadata describing the data source.

The Physical data 2 and Physical Data 3 tabs allow updating of further default values, including the proportions of catchment runoff entering various parts of the catchment river system. WQ2000 includes default values for water release from the major reservoir. This can be defined as either a fixed minimum compensation discharge or as a prepared monthly discharge time series file.

#### Metadata

The default database contains metadata describing the data sources. Metadata is required for each change that is made. A metadata summary can be edited via the View menu. The File menu also makes provision to generate a file containing metadata for all the changes made to the default data values. This file can then be sent to the DWAF's User Support System to facilitate evaluation and future updates of the default database.

#### System diagram

Figure 4 shows the standard system network used by WQ2000 to represent the selected quaternary catchment. It is a simplification of the system network used by the WQT model. Numbers enclosed in square brackets precede the field descriptions shown in Figure 3. These refer to numbered points in the system diagram (Figure 4), which can be accessed by pressing the "System Diagram" button at the bottom right of the window.

The bottom half of Figure 4 represents the quaternary itself, while the top half represents the cumulative upstream catchment feeding into it. The quaternary catchment network comprises one catchment washoff module [node 13], with a proportion [P1] of its runoff allocated to an aggregated minor dam [node 9] that regulates supply to part of the irrigation area [node 10] and part of the runoff [P2] is available to opportunistic irrigation areas [node 11]. The remainder of the catchment runoff bypasses both the minor dam and unregulated irrigation. The minor dam is an aggregation of small farm and municipal dams located off the main river channel. A point source abstraction [route 5] can be specified for this dam. The flow from these nodes is combined in a channel reach [node 1], which also receives mine pumpage [route 7] and is subject to bed loss [2]. The channel reach node simulates wetland evapotranspiration processes. A portion [P3] of the outflow from the channel reach is discharged below a major dam [node 8], the rest entering above this dam. The major dam receives effluent discharge [3], inflow from the upstream system [16], stored upstream catchment inflow [15] and water importation [6]. Water demand [4] is abstracted from the major dam, which also has a specified minimum release. An irrigation module [node 12] is supported from the upstream main river system, which is regulated by the major dams. Route [14] is the final outflow at the lower end of the quaternary catchment. Files of simulated monthly outflow and salinity via route [14] can be stored. The stored output then becomes part of the defined input [route 15] for the immediate downstream quaternary catchment.

The network for the upstream river system (i.e. the top half of Figure 4) is similar to that for the quaternary catchment. However, in this case the nodes and their associated hydrological time series files are flow- or area-weighted aggregates for the upstream quaternary catchments. Further down the system, when the selected catchment is separated from the defined flow by one or more quaternary catchments, the defined flows become part of the inflow to the upper sub-system.

### Model simulation

After selection of a quaternary catchment and any desired editing of default development values, the WQT hydro-salinity model simulates seventy years of monthly hydrology for natural and present day developed conditions for both the off-channel case and taking account of the cumulative inflow from upstream catchments. These four simulations are run seamlessly and invisibly without the user needing any expertise in using the complex WQT model.

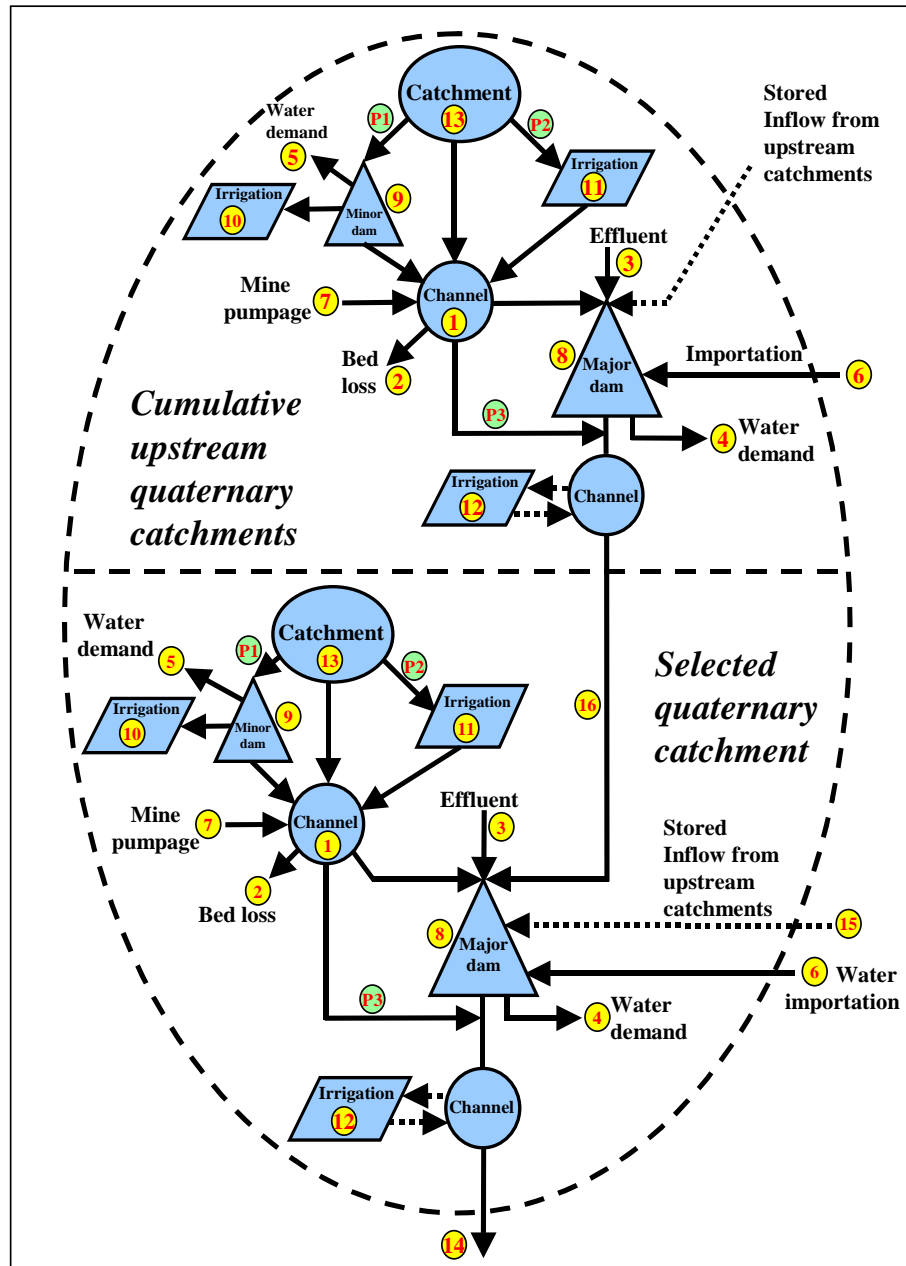


Figure 4: Selection of quaternary

### Reporting

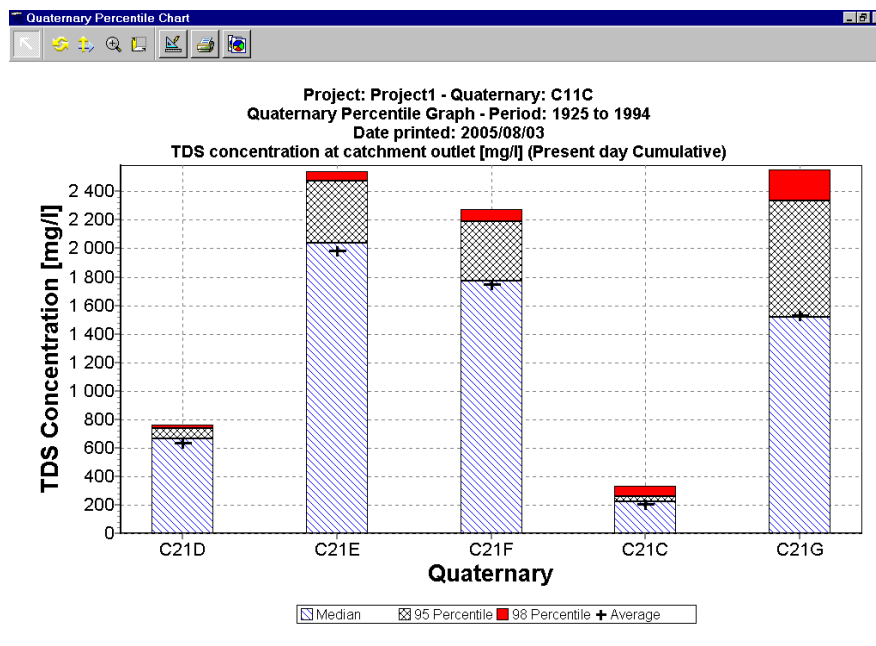
A result summary report for the quaternary catchment simulation can be generated. This contains all the run definition data (to identify the summary sheet) and the simulation results for natural and present day conditions with and without the effect of inflows from upstream catchments. The following results are reported:

- Average outflow Total Dissolved Salts (TDS) concentration (via route 14)
- Median outflow TDS concentration (via route 14)
- 95 percentile outflow TDS concentration (via route 14)
- 98 percentile outflow TDS concentration (via route 14)
- Flow-weighted average outflow TDS concentration (via route 14)
- Average catchment runoff volume (runoff from node 13 before alteration by channel and reservoir storage, irrigation, point inflow or abstraction)
- Average catchment runoff TDS concentration (runoff from node 13)
- Average TDS concentration in major dam (node 8)
- Flow-weighted average TDS concentration of spillage from major Dam (node 8)
- Mean annual outflow volume from quaternary catchment (via route 14).

### Graphical display

The following four types of plot can be used to display the simulation results:

- Time series plot of monthly TDS concentration and/or flow at selected key points in the system
- Duration curves of monthly TDS concentration at one or more selected points
- Seasonal distribution of median or average TDS monthly TDS concentration
- Stacked bar chart of 98-percentile, 95-percentile, median and average monthly TDS concentrations at a selected key point in selected quaternary catchments. Figure 5 is an example of such a plot for the Suikerbosrand / Blesbokspuit catchment.

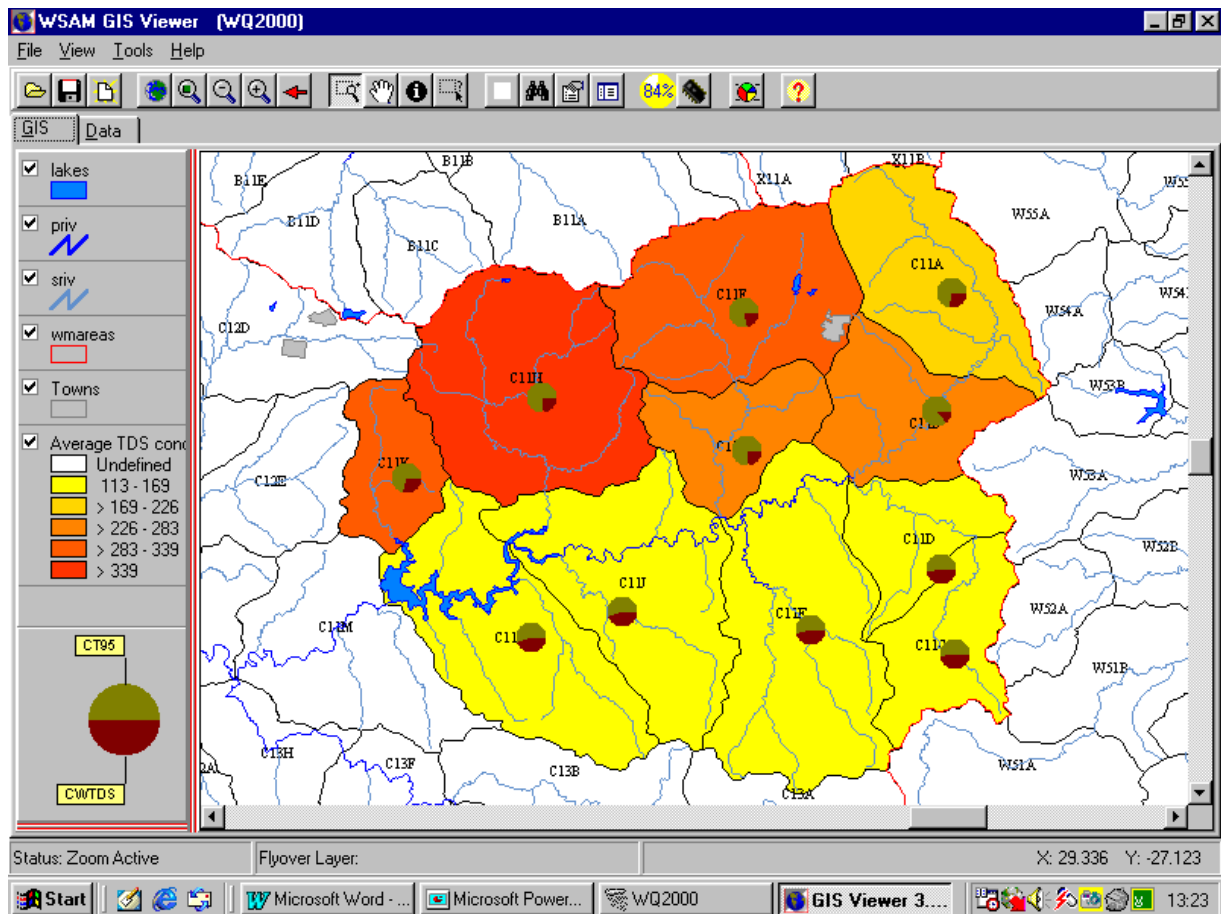


**Figure 5: Quaternary percentile plot**

### Regional overview

The DWAF GIS Viewer can be selected from the Map menu option. This facilitates a catchment wide overview by shading each quaternary catchment in a chosen area according to the magnitude of the selected variable. Figure 6 is an example showing the present day distribution of average TDS concentration in the catchment above Grootdraai Dam.

In the example each quaternary catchment has been shaded to reflect the average simulated TDS concentration of the cumulative runoff at its outlet. Two variables have also been included in the pie diagram shown in each quaternary catchment. The variables selected in this case are the average and 95 percentile TDS concentrations simulated at the catchment outlet. Up to three variables can be included in the pie charts.



**Figure 6: GIS Viewer area plot of average TDS concentration**

Various WQT model parameter values (such as the calibrated catchment salt generation rate and the salt washoff efficiency factor) could have been selected for the area plot and pie charts. The plot could also have been generated for incremental catchment conditions, excluding the effect of inflows from upstream quaternary catchments.

A display of the linkage of sub-catchments upstream of the selected quaternary catchment can also be accessed from the Map menu option.

## WQT MODEL

The WQT model is the invisible engine at the heart of WQ2000. This is a modular monthly time step hydro-salinity model. A system network is defined linking model nodes (sub-modules) by means of flow routes. The order in which upstream reservoirs are called on to meet downstream water demands is controlled by penalties assigned to each flow route and reservoir storage zone. Figure 4 is a simplified version of the system network used in WQ2000.

The following six types of model node are included in WQT:



### Salt Washoff module

The catchment salt washoff module simulates the gradual accumulation of soluble solids within a catchment, their storage and subsequent release during runoff events. Account is taken of both pervious and paved urban catchment surfaces. For pervious surfaces the model simulates the movement of salt via direct surface runoff, infiltration, interflow, sub-surface storage and groundwater flow. Provision is made for the growth of paved urban surfaces and diffuse source salt recharge.

### Channel Reach module

The channel reach sub-model simulates the movement of water and salt through a river reach. The upstream end of the river reach may accept input from up to five source routes. It can also accept a portion of the catchment runoff and salt washoff from an associated catchment salt washoff module. Files of monthly discharges and salt concentrations from mine de-watering may also be specified. Account is taken of riverbed loss and evapotranspiration loss from wetlands. Allowance is made for growth in wetland area, with linear or exponential growth interpolation between break point years for which areas are specified. The accumulation of salt in wetlands during periods when the potential net evaporation loss exceeds the upstream inflow is also accounted for, with the release of such salts during subsequent flood events. Each channel reach has one downstream outflow route.

An irrigation module may also be associated with the channel reach, to represent riparian irrigation. The irrigation demand is abstracted from the channel and the return seepage discharged to the channel sub-model outflow route.

### Irrigation module

The irrigation sub-model simulates the accumulation of salt within irrigated lands and its release via return seepage. The irrigated land is modelled as a two layered system. Allowance is made for additional flushing during wet periods. The following processes are simulated:

- Canal transmission losses
- Annual maximum permissible water allocation and its growth or reduction
- Multiple crops (up to 20 may be specified)
- Additional return flow during wet periods
- Losses to relatively inaccessible deep-seated ground water.
- Addition of salts via agricultural lime, gypsum or fertiliser
- Growth or reduction of irrigated area with time
- Variable effective rainfall reduction factors (as function of rainfall intensity)
- Return seepage from two sub-surface zones and via surface spillage from canal ends.

The irrigation module is associated with a catchment salt washoff module. As the irrigated area increases, land (and the salt it contains) is transferred to the irrigation model. As irrigated land is taken out of service, the land (and its associated salt) is transferred back to the catchment salt washoff model. Linear or exponential interpolation can be used to calculate irrigation areas for years between those for which areas are specified. When the water supply is curtailed the assumption is that the area of land under irrigation is reduced, with part of the land lying fallow. Normal catchment soil evapotranspiration is assumed to apply to fallow areas, until such time as the water availability allows irrigation of the full area to resume. The salt balance is maintained.

The irrigation model can be defined as dependent on a channel reach, or as an independent node with its own water supply and return seepage routes.

### Reservoir module

The reservoir sub-model simulates the monthly water and salt balance of a dam. Account is taken of evaporation loss, rainfall, abstraction and release and spillage driven by inflows to the reservoir. Complete mixing within the reservoir is assumed. This is a reasonable assumption for most reservoirs and the relatively long monthly computational time step.



The water and salt balance equations have been set up in such a manner that a reservoir can be included as part of a dependent salt feedback loop. This facilitates the recycling of salt when water abstracted from the dependent reservoir is supplied to a demand centre, which in turn returns salt-enriched effluent to tributaries draining back into the reservoir. This feature is not used in WQ2000

#### Junction node

The junction module simply mixes together the inflows from up to five upstream routes and distributes the outflow to up to five downstream routes. A later enhancement allows for blending, whereby the inflow through preferential routes is adjusted to prevent the outflow TDS concentration from exceeding a defined blending target. Constraints on the capacity of flow routes can also be set. This feature is not required in WQ2000.

#### Demand Centre module

The demand centre sub-model simulates the supply of water to meet specified monthly gross water demands and the return of effluent, enriched with salt added during use. The effect of monthly climatic variation on the percentage return flow is simulated. Provision is made for the direct recycling of effluent, with or without desalination. The demand centre may form part of a larger dependent feedback cycle that spans a number of system elements including one dependent reservoir. Each demand centre may accept inputs from up to five source routes, each of which may be independent, or part of the dependent feedback cycle. The simulated monthly effluent discharge and salt load is apportioned to up to five return flow routes.

The standard WQ2000 model system layout does not include any demand centre nodes.

### **CATCHMENT AGGREGATION**

When a quaternary catchment is selected WQ2000 aggregates all upstream quaternary catchment nodes and hydrological files until a defined output is encountered. More than one such defined inflow can occur in a branched river system. When this occurs the defined flow and salinity files are also aggregated. The distribution disk containing the default database comes with defined flow files spaced regularly throughout the Vaal River system. This has been done to speed up the aggregation process after selection of a new quaternary catchment.

All 192 quaternary catchments of the Vaal catchment have also been simulated for the original default conditions and the key results stored in the base dataset. This has been done to permit the generation of regional overview maps using the GIS Viewer without having to first simulate every quaternary catchment. However, after changes to a quaternary catchment have been saved, all downstream quaternary catchments are flagged as no longer having been simulated. This is because cumulative inflow to such quaternaries will then be altered. Any defined downstream flows are also flagged. Thereafter, if a downstream quaternary catchment is selected for simulation, the model will first re-simulate the relevant affected quaternary catchments to re-generate all defined time series files. Similarly, before producing a regional overview map using the GIS Viewer, WQ2000 will automatically re-simulate all flagged quaternary catchments in the specified area to be mapped.

### **PRACTICAL APPLICATION**

WQ2000 has already been used in a study to assess the expected salinity regime in a proposed  $168 \times 10^6 \text{m}^3$  capacity dam in the Klip River catchment to augment the water supply to Sasol 2/3 complex and Eskom power stations supplied from Grootdraai Dam. Initial examination of the water quality data available at a river monitoring station near the proposed dam site revealed unexpectedly high salinity, with an average TDS concentration of 172 mg/l and a 95-percentile concentration of 282 mg/l. Rapid application of WQ2000 showed that the net effect of dilution by floodwater stored in the dam and evaporative concentration would reduce the average TDS concentration to 130 mg/l and the 95-percentile peak to 148 mg/l. Without the availability of WQ2000 considerable time and effort would have had to be invested to obtain this result.

Further investigation followed to determine the 2030-projected effect of atmospheric deposition, since a distinct upward trend in sulphate concentration was evident in the historical database. The effect on the transferred water from the new dam to Grootdraai Dam was also investigated<sup>(9)</sup>. Although WQ2000 was not used to model this more complex system, the relevant WQT model parameter files were taken from the WQ2000 database. Hence, even for this more detailed investigation for which WQ2000 was not used directly to simulate options, significant savings were realised by making use of the features of WQ2000.

## **TRAINING AND USER SUPPORT**

Two training sessions have been held under the joint auspices of the Water Research Commission and the DWAF. The DWAF is planning further training for 2005. The DWAF has incorporated WQ2000 in its User Support System, which will provide a means of:

- Receiving user queries and disseminating feedback
- Collating and evaluating information on changes to the database
- Maintaining training records
- Notification of training courses and other events
- Dissemination of software and database updates
- Version and access control.

## **DISCUSSION AND CONCLUSIONS**

WQ2000 facilitates changes to any of the default values to reflect anticipated catchment development or to test the impact of planned developments, such as a new dam or changed effluent discharge. This places a powerful, rapid and cost effective assessment tool in the hands of a wide range of practitioners.

### Model use

It is envisaged that licensing authorities and planners would use WQ2000 to make an initial rapid assessment of the effect on salinity of expected or planned development. This would provide a first level sifting of options. At this stage some of the most promising options could be selected prior to more detailed analyses. Further examination of salinity would not be required in those cases where salinity impacts are shown to be negligible or acceptable. Options showing more significant impact would be identified as requiring more detailed examination.

The limited resources available to supply water and sanitation to smaller communities are usually not sufficient to cover the cost of detailed water quality studies. Up to now there has not been a low cost alternative. As a result scant attention has been paid to such impacts. WQ2000 makes it feasible to assess the salinity impacts of even the smallest development schemes. As such WQ2000 is a valuable companion of the WR90<sup>(10)</sup> water resources manuals and the WR2005 electronic system that is under development.

The extensive quaternary scale database provides WQT model calibration parameters and data files and catchment development data. Provision is made to access all of the WQT model data files. Thus when more detailed modelling is required an experienced modeller has ready access to prepared and calibrated WQT model data files for the area of interest. These files can then be modified to reflect the more detailed system layout. This again offers substantial saving.

WQ2000's simulation modelling concept combined with use of the DWAF GIS Viewer also played a major role in determining the course of the WQR2005 development.

### Limitations

WQ2000 is limited by the following factors:

- It has been set up only for the Vaal River catchment.
- It handles only TDS
- It is not suitable for large systems spanning more than two major dams.

### Model enhancement and extension

The following enhancements are envisaged:

*Extension of coverage:* Having completed the model development and its subsequent enhancement, the next envisaged step is to extend the coverage to the rest of the country. This should start with those areas where salinity modelling has already formed a part of DWAF system analyses. This is logical because the WQT model has already been calibrated for such systems. Moreover, these represent the areas where salinity is of concern. A much coarser coverage will be appropriate for the remaining portion of the country.

*Other water quality variables:* At present the DWAF system analyses include only salinity modelling (i.e. TDS) and one instance where sulphate modelling is used. This is because the persistence of salts renders TDS the most economically important water quality problem associated with development and the prevalent aridity of South Africa. Conservative pollutants are also the most amenable to reliable modelling. While other pollutants cannot be ignored, it would not be appropriate to model them in WQ2000 to the same degree of detail as for TDS. Another WRC project is underway to develop WR2005, the successor to the WR90 hydrological database. An overview of water quality will be included in the WR2005 database. This will be much more simplified than the approach used in WQ2000, but it will address a wider range of water quality variables. This could form the kernel for extending the coverage of WQ2000 to other water quality variables.

*Large system modelling:* There is no intention to enhance the model to address the last bulleted limitation. WQ2000 was never intended to replace existing detailed system models that have been set up for systems spanning several major inter-connected dams.

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